



NOAA/USDA  
Alternative Feeds Initiative

# The Future of Aquafeeds

November 2010



Public Comment  
for  
DRAFT

This draft report is now out for final public comment before being published by the agencies. The public comment period will begin on November 18, 2010 and end on February 18, 2011. We would prefer comments submitted electronically via the NOAA Aquaculture Program home page—<http://aquaculture.noaa.gov>. Other comments (non-electronic) should be faxed to the NOAA Aquaculture Program clearly marked “Attn: Alternative Feeds Initiative” at (301) 713-9108; or mailed to the NOAA Aquaculture Program, Attn: Alternative Feeds Initiative, 1315 East-West Highway, Rm. 13117, Silver Spring, MD 20910.

**Disclaimer: The views represented in this report are the views of the participants in the meetings and of the authors. They do not necessarily represent the views or official policies of the sponsoring agencies.**

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**NOAA/USDA  
Alternative Feeds Initiative**

# **The Future of Aquafeeds**

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**November 2010**

**RAFT**  
for Public Comment

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# Foreword

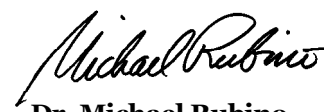
The National Oceanic and Atmospheric Administration (NOAA) and the Agricultural Research Service and National Institute of Food and Agriculture of the U.S. Department of Agriculture (USDA) are pleased to provide this federal interagency report, *The Future of Aquafeeds*, for public comment.

This report was prepared as part of the ongoing NOAA-USDA *Alternative Feeds Initiative* which was launched in 2007. The purpose of the initiative is to accelerate the development and use of alternative dietary ingredients that will reduce the amount of fishmeal and fish oil in aquaculture feeds while maintaining the important human health benefits of diverse aquaculture food products. Ultimately, the initiative will lead to the discovery and commercialization of improved alternative feeds which will result in reduced dependence on marine fishery resources by feed manufacturers and aquaculture producers worldwide. These developments are critical to the long-term sustainable growth of aquaculture in the United States and abroad to meet projected increases in consumer demand for safe, high quality farmed aquatic foods.

NOAA, USDA, and other federal agencies contribute vital support for research, development, and the transfer of alternative feeds technology to industry. This report provides a comprehensive perspective on the current state of knowledge and the challenges and opportunities associated with discovery, development, and commercial use of various feed ingredient alternatives. It was prepared by assembling experts from government, academia, private business, non-profit organizations, and other stakeholders in workshops which examined the economic, human health, environmental, and practical implications of various alternative feedstuff options.

The report also summarizes priorities and future directions for feeds manufacturing and includes seven case studies featuring some of the most promising research on alternative feeds being conducted today along with examples of successful alternatives and how they are being used.

The findings, recommendations, and research priorities contained in this report help inform ongoing research and priorities for new research to be supported by NOAA, USDA, and other public and private partners under the joint federal *Initiative*. We look forward to your thoughtful comments on this report.



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# Acknowledgements

When the NOAA-USDA Alternative Feeds Initiative kicked off in late 2007, the purpose was clear and the task was daunting. The initiative set out to identify and understand what was needed to develop, and commercialize promising alternative dietary ingredients for aquaculture feeds. Ingredients are needed that would reduce the amount of fish meal and fish oil from forage fish contained in aquaculture feeds while maintaining the important human health benefits of farmed seafood. Ultimately, the NOAA-USDA initiative will lead to reduced dependence on marine fish resources by feed manufacturers and seafood farmers worldwide. It's clear that the initiative strengthened an already solid bond among NOAA and the two USDA agencies, the Agricultural Research Service and the National Institute of Food and Agriculture (formerly CSREES). As the initiative matured, these agencies were greatly aided by help and advice from scientists and others within the Department of the Interior (DOI) and the Food and Drug Administration (FDA). Now, with the publication of this final draft, special acknowledgement goes to the writing team which was led by Dr. Michael B. Rust of the NOAA Fisheries Service Northwest Fisheries Science Center and included Dr. Fredric T. Barrows of USDA's Agricultural Research Service, Dr. Ronald W. Hardy of the University of Idaho's Aquaculture Research Institute, Dr. Andrew Lazur of the University of Maryland's Center for Environmental Science and Maryland Sea Grant, Kate Naughten of the NOAA Aquaculture Program, and Dr. Jeffrey Silverstein of USDA's Agricultural Research Service.

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# Executive summary

## Background

In 2007, the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Agriculture (USDA) began a detailed and inclusive consultation with independent experts, government researchers, stakeholders, and the general public to gather and distill information on alternative feeds for aquaculture. The driver for this effort was, and continues to be agency and stakeholder interest in speeding up the development and commercialization of viable alternatives to the fish meal and fish oil used in aquaculture. The goal of the NOAA-USDA initiative is to identify and prioritize research to develop feeds that will ultimately reduce reliance on wild reduction fisheries, maintain the human health benefits of farmed fish, and allow the aquaculture industry to expand in a sustainable manner. For this development to be realistic, the alternative also has to be economically viable. Thus we considered a triple bottom line in our evaluation of alternatives. These bottom lines take in to account the economic, environmental and human health implications (Figure 1) of alternative feed ingredients.

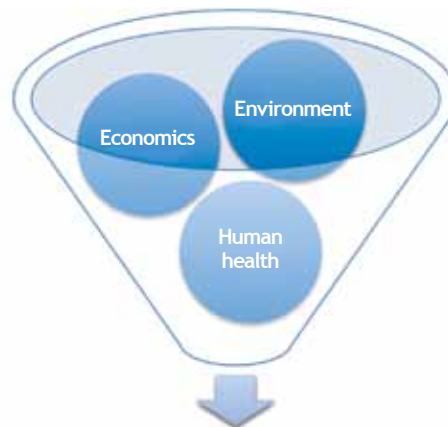


Figure 1

## Feeds for Healthy Sustainable Aquaculture

North America is the worlds largest and most advanced producer of formulated animal diets (followed by the European Union and then China). As a world leader in this area, development and approaches



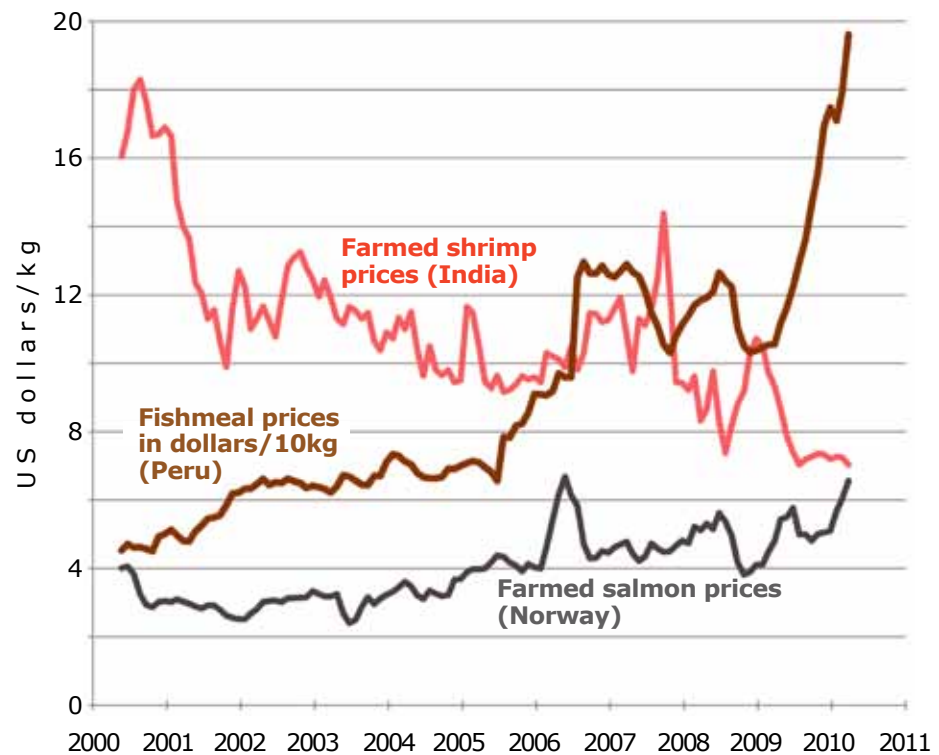
to fish feeds that happen in the United States will help drive change worldwide. It is important to note that even though the US has a relatively small aquaculture sector, developments in aquaculture feeds and advances in technologies and ingredients will have world-wide importance and impact. Currently, the production of feeds for aquaculture worldwide is the most rapidly expanding market in the animal feeds production sector increasing 6-8 percent per year. Aquaculture feeds could represent significant export opportunities for the US feeds sector and their suppliers.

In the United States and worldwide, the development and commercialization of alternative feeds are crucial to the expansion of sustainable finfish and shrimp aquaculture production. Currently, fish meal and fish oil are largely made from small pelagic or reduction fisheries such as anchovies, menhaden, and sardines and from the trimmings of fish processing (both from wild-caught and aquaculture sources). Although the world production of fish meal and fish oil has been relatively constant for the past 20 years, the percentage consumed by aquaculture has risen, now accounting for 60 to 70 percent of the annual production of fish meal and 80 to 90 percent of the annual production of fish oil. Feed for chicken, pork, and pets account for most of the rest, with an increasing percentage of fish oil now going to humans. Pelagic fish are also consumed directly by humans and are used to bait lobster, crab, and fish traps and hooks in commercial and recreational fisheries. As stocks of pelagic or reduction fisheries used for feed, direct consumption, and bait are limited and already fully utilized, alternate sources of protein and oil are needed for aquaculture feeds. As a potential indication of limited supply, the price of fish meal roughly tripled between 2002 and 2010, and supply remains limited while the demand for fish feed ingredients is expected to continue to rise (Figure 2). At the same time, prices for farmed salmon and shrimp have been steady or even declined.

Environmental considerations also limit supply. Pelagic fish provide important ecosystem benefits to the marine environment. Although most industrial fisheries are regulated by catch limits, increased demand for use of forage fish in direct human consumption, for bait, for use in aquaculture and agriculture could provide an incentive to over exploit these fisheries, with negative consequences for the marine environment. Also, changes in fisheries management may further limit supplies of forage fish available. In particular, fisheries managed according to single species



## Executive summary



**Figure 2**  
Changes in prices of fishmeal, farmed salmon, and farmed shrimp from 2000-2010.

sustainable yield measures may not be sustainable from an ecosystem perspective if the importance of forage fish to other animals in the ecosystem is not accounted for. Catch limits or quotas may be reduced to leave a greater supply of forage fish in the oceans to support ecosystem functions.

Developing alternatives to fish meal and fish oil is a global challenge for several reasons. Fish meal and fish oil are worldwide commodities. Asia consumes the majority of fish meal, Europe (especially Norway) is the dominant consumer of fish oil, and South America produces the bulk of both fish meal and fish oil. Fish meal and fish oil are commodities that are traded worldwide. The US is a small player in this market with little control over prices or quantities sold. In addition, the concentrated nature of the product makes supply vulnerable to perturbation, as evidenced by the recent earthquake in Chile.



The United States is a small net exporter of fish meal and oil. In 2007 the United States used about 190,000 metric tons of fish meal and 38,250 metric tons of fish oil. Net exports were about 65,500 metric tons of fish meal and 31,000 metric tons of fish oil. Consumption in the United States is mostly for feeds for all types of livestock and pets. A portion of the catch of menhaden, sardines, and anchovies are used for bait for commercial and recreational fishing, fish oil tablets for human consumption, and fertilizer. The majority of fishmeal produced in the United States comes from menhaden, caught in the Gulf and Atlantic followed by meal made from the processing wastes of whitefish caught for human consumption from Alaska. Given the Gulf oil spill, it is unclear if the US will remain an exporter due to the potential impacts of oil on gulf menhaden stocks. Therefore, the need to develop alternatives is pressing for both domestic and worldwide use.

This global challenge also represents an opportunity for US agriculture products and other alternative feed ingredients, particularly in supplying Asia where most aquaculture production occurs. The opportunities for US feed and feedstuff suppliers could be significant, and the United States is well poised to take advantage of this opportunity due to our strong agriculture production sector, quality fish nutrition labs, and developed feeds infrastructure.

In November 2007, NOAA and USDA launched the Alternative Feeds Initiative with a solicitation for public comments on several specific questions related to alternative feeds for aquaculture. The questions, which were published in a Federal Register notice included the following:

1. Where should the federal government focus its research efforts in the area of alternative feeds for aquaculture? Are there specific areas that the federal government should not address?
2. What are potential alternative sources of protein and oil for aquaculture feeds? For example, are there specific opportunities for greater use of seafood processing waste and other agricultural by-products in aquaculture feeds? Are there specific obstacles to using these alternatives as alternative dietary ingredients in aquaculture feed?
3. What type of treatments or processes show promise for improvement of existing aquaculture feedstuffs and for developing new feedstuffs? How soon could these technologies be commercialized?



## Executive summary

4. Fish meal and fish oil contribute important human nutritional components to aquaculture feeds such as omega-3 fatty acids. As the aquaculture feeds industry seeks to replace fish meal and fish oil with alternatives, how can the nutritional benefits of farmed seafood be maintained or enhanced? For example, what technologies exist for producing omega-3 fatty acids?

Following the initial public comment phase, NOAA and USDA assembled expert panels to address these same four questions and to identify other issues for consideration in the preparation of a rational, fact-based plan to identify and prioritize research and development needs. The initiative's first panel was composed of scientists with expertise in feeds and feed ingredient research, fish and human nutrition, bioenergy, processing, agriculture, and related areas. The second panel was composed of stakeholders from academia, industry, non-government organizations, and government who had expertise and/or interest in the topic. Government officials with responsibility for research, funding priorities, regulations, and policy observed panel workshops.

In addition to answering the Federal Register questions, panels were asked to identify constraints and concerns about feed ingredients—those currently in use and those that might be used in the future. Panels were also asked to identify possible solutions to the challenge of replacing fish meal and fish oil in future feeds, identify key research and technological challenges associated with developing viable alternate protein and oil sources, and predict the future of feeds for aquaculture—specifically, the challenges and changes that aquaculture will face and the developments that will affect both producers and consumers in next 5 years and in the next 25 years.

A brief summary of panel findings and conclusions follows. Several researchers and other experts were also asked to develop short case studies to highlight specific advances being made in the development of alternative ingredients. Those case studies are included right after the summary of findings.



**1. *Fish meal and fish oil are not nutritionally required for farmed fish to grow.***

About 40 nutrients—such as essential amino acids, vitamins, minerals, and fatty acids—are required but they can be obtained from sources other than fish meal and fish oil. Fish meal and fish oil have been the preferred ingredients in fish feeds because they contain these nutrients in nearly perfect balance, are easily digestible by the fish, result in good growth and survival, and provide human health benefits. Combining other ingredients to get the same balance is possible, but will require fully understood fish requirements and alternative performance.

**2. *Farming of fish is a very efficient way to produce animal protein and other human nutritional needs.***

Farmed fish use their feed very efficiently. For example, farmed Atlantic salmon can convert approximately one kilogram of feed (dry) into one kilogram of flesh (wet). In contrast, the feed conversion of poultry is 3-5:1, and pork is 8:1. Fish need fewer calories because they are cold-blooded and they do not need to support their weight.

**3. *Feed manufacturers making diets for carnivorous fish and shrimp have already reduced their reliance on fish meal and fish oil.***

Application of previous research led to cost-effective substitution using alternatives, which helped mitigate feed costs in the face of increasing fish meal prices (see Figure 2 on page 2). In the past 15 years the ratio of fish in to fish out has dropped from 3-4:1 to approximately 1.5:1 for major aquaculture species due to increased use of protein and oils in diets from non-marine sources. Fish meal and fish oil are likely to be increasingly reserved for use in specialty diets (broodstock and larval diets) and finishing diets to maintain the human health benefits of farmed seafood.

**4. *Economics is currently the major driver of using alternate feed ingredients in feed mills.***

Feed producers make substitutions for fish meal and fish oil according to how their price compares with allowable alternatives (i.e., alternatives for which sufficient nutritional and production knowledge and experience exists to allow their use). Panels identified some crucial factors limiting changes to feed formulations, including insufficient information on nutrient requirements of farmed species, especially newly domesticated species, and on available nutrient content and nutritional value of alternative ingredients for fish and shrimp. This area requires investments in research to help feed producers understand the costs and benefits of including alternative ingredients in aquaculture feeds.

## Summary of findings

### ***5. The net environmental effects of the production and use of alternate feeds should be considered.***

Consideration should be given to the environmental impacts of making dietary changes to feeds for farmed aquatic organisms.

### ***6. The human health implications of using alternative feeds needs to be better understood and considered.***

Long chain omega-3 fatty acids and other nutritional compounds found in fish meal and fish oil provide important human health benefits. Seafood reared on alternative feeds must continue to provide these health benefits to consumers. Human health considerations should be addressed along with economic and environmental considerations when alternatives are considered. To accomplish this, fish nutritionists should work with human nutritionists and food scientists on promising alternative ingredients to determine impacts of alternatives on final product quality.

### ***7. Fish meal and fish oil are minor contributors to the world protein and edible oil supply.***

In 2007, fish meal accounted for approximately 2.3 percent of total protein meals and fish oil for about 2.0 percent of total edible oils. The largest supply of protein on Earth is from soybeans. A 4 percent increase in soy protein meals would nearly equal the total world fish meal supply. An increase in the amount of soy protein equal to world fish meal annual production has been achieved about every 5 years without any additional cropland, based on historical increases in yield per acre due to intensification, new cultivars, and farming practices.

### ***8. Recovery and utilization of fisheries processing waste should be encouraged and increased.***

This material has been shown to produce products of similar biological value to fish meals and oils made from industrial fisheries. The total worldwide amount of fish processing waste from wild capture and aquaculture may equal the amount of forage fish used for fish meal and fish oil from industrial fisheries. But fish processing waste is often not economical to capture because of logistical and technical constraints. Research and financing is needed to help capture the waste products from wild capture fisheries that often are located in remote or inaccessible regions with poor infrastructure. Likewise, research to capture and reuse the waste products from aquaculture should be undertaken. The use of processing waste from aquacultured organisms to produce fish meal and fish oil eventually could make aquaculture a net producer of fish meal and oil.

**9. *Plants produce the vast majority of protein and edible oils in the world, accounting for 94 percent of total protein production and 86 percent of total edible oil production.***

Plants also make up a substantial proportion of diets for carnivorous fish (e.g., 50-60 percent of a typical salmon diet). It is likely that plants will deliver the bulk of amino acids and fats to diets for farmed fish in the future due to abundance, the potential for increased production, and low cost. Research to increase the use of sustainable plant products in feeds for aquatic organisms will help to increase the importance of agriculture to aquaculture and vice versa. This area of research would be as important to farmers as to aquaculturists and may represent a significant opportunity for American farmers.

**10. *Algae-based biofuel may present opportunities for feed ingredient production because protein is a byproduct of oil recovery from algae, and marine algae produce the long chain omega-3 fatty acids and certain amino acids important to fish and human health.***

It is too early to understand the ramifications of increased algae biomass production for fish diets, and this area will require communication between algae biofuel scientists and fish nutritionists. Support of research in this area is justified for producing the long chain omega-3 fatty acids alone; a potentially higher value product than biofuel.

**11. *There will likely be increased demand for and production of ethanol and bioplastics. Byproducts from these industries could make good ingredients for fish diets.***

Fish feeds are mostly made up of protein and oils. Ethanol and some bio-plastic are made from the carbohydrate fraction of plants, leaving behind the protein and oils. Future biofuel production may be quite different from today's focus on ethanol made from corn carbohydrates, which uses a process that degrades the quality of protein waste products. If grain remains a feedstock for ethanol production, new approaches to recover high-quality protein and oil from the ethanol production process will be needed to make it suitable for wide spread use in fish feeds. Biodiesel is made from the oil fraction, leaving behind concentrated protein that is already suitable for fish. Fish nutrition researchers should work, and coordinate with, biofuel scientists to ensure byproducts are safe and usable for fish. Research that supports processes resulting in high-quality protein and oil byproducts of fuels production should be encouraged.

***12. As replacements, many alternatives are higher in cost per unit fish gain (biological value) than fish meal and fish oil.***

However, the recent trend (since 2006) has been for fish meal and fish oil prices to increase faster than prices of alternative protein and oil sources. Research that can help lower costs or improve the biological value, without raising costs, will increase the rate of fish meal and fish oil replacement.

***13. Fish have dietary needs and preferences for specific compounds not found in plants, so there is a need for specialized products that supply these compounds and/or add flavor to the diet.***

These ingredients will likely be higher in cost than the bulk protein and oil products and will need to contain flavors, nutrients, or properties not found in bulk proteins and oils but which are needed for fast growth, health or increase consumption. Examples are algae, invertebrates, animal by-products and seafood trimming meals and oils. Additional ingredients such immune system enhancers are also beneficial to enable use of higher levels of alternatives. Research is needed to develop materials that will enable greater use of cheaper more abundant protein meals and oils.

***14. Alternative sources of protein and oil are common commodities used in livestock and companion animal feeds and come from novel byproducts from other industries, underutilized resources, or completely novel products.***

- Existing commodities that have the potential for greater use in feeds include protein concentrates from grains or oilseeds and byproducts from animal proteins.
- Novel byproducts from other industries include proteins recovered from biofuel production or single-cell proteins produced from inexpensive carbon sources.
- Other sources include fish processing wastes, trimmings and/or bycatch from fishing.
- New products including meals produced from worms, insects, and marine invertebrates, and meals and oils from algae.

What these products have in common is that they are underused and/or underdeveloped protein and oil sources that require variable degrees of investment in research and development to become more widely used. Some possess attributes that are detrimental to fish (e.g., anti-nutrients), or they contain insufficient levels of essential or semi-essential nutrients and need to be processed, blended with complementary products or supplemented. More information is also needed to evaluate the environmental impacts associated with using various feed ingredients. Information on

contaminant content of alternate products is also needed to place risks and benefits to fish wellness and human health into a rational context. Coupled with this is the opportunity to maintain or improve the safety and healthfulness of farmed fish products for the consumer by using alternate ingredients. All these topics will require investments in research and development.

**15. *Plants and other alternatives contain some compounds (anti-nutrients) that are detrimental to fish.***

Although there are processes to remove or inactivate many of these compounds, further research and development is necessary to improve these processes. Fish may also be selectively bred to be relatively more tolerant of the anti-nutrients in some alternatives.

**16. *Harvest of lower trophic level species, such as krill, for fish meal and oil production may be possible, but the environmental benefits afforded to the marine ecosystem from these species should be considered along with the economic and nutritional aspects of their use.***

While this may provide an option in the near term, the harvest of any wild population, including krill, would require careful management and would be limited to what nature can supply.

**17. *The use of bycatch for production of fish meal and fish oil could provide a substantial amount of these products without increasing the current impact from the wild capture fisheries.***

Although traditional processes exist to convert bycatch into fish meal and fish oil, concerns over creating a market for non-target species and the logistical issues associated with dealing with retained bycatch at sea have been expressed.

**18. *Demand for long chain omega-3 fatty acids for both direct human consumption and feed ingredients is likely to increase beyond the amounts available from marine resources.***

Alternative sources are needed and should be developed, such as algae, microorganisms, and/or oilseeds. More efficient use of long chain omega-3 fatty acids can be made in aquaculture through improvements in feeding practices and formulation. Research leading to new cost-effective sources of long chain omega-3 fatty acids will benefit human health as well. Research to improve production and the efficiency of use should also be supported.

## Summary of findings

***19. Farmed fish species are being increasingly domesticated and performance is improving through conventional genetic selection and selection for performance on plant-based and other non-fish based aquafeeds.***

As aquatic species are domesticated, selection can be directed toward better use of non-fish meal and non-fish-oil ingredients.

***20. Scientific information on the nutritional requirements of farmed fish species, and feed ingredients, and the interaction between the fish and the diet, will need to expand greatly to make substantial improvements in feed formulation by commercial aquaculture feed producers.***

Updating the National Research Council (NRC) requirements for fish on a regular basis and support for research that helps define the basic nutritional requirements for farmed aquatic species should be supported.